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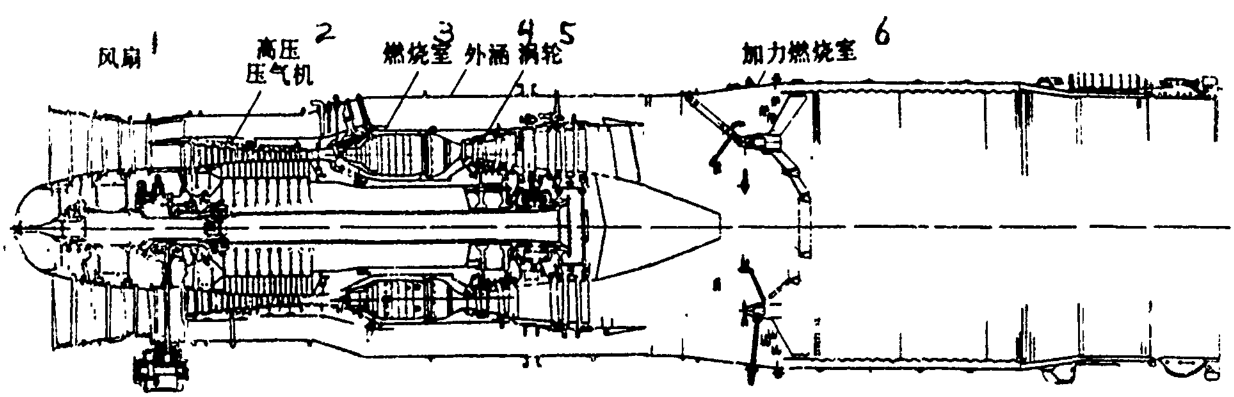
WS6 - The Demonstration of a First-Generation Augmented Turbofan Engine of China

A first demonstrator of the augmented turbofan engine was developed in the 60's and was named WS6 (see figure). The engine had a mid-level thrust of 71.2 kN and a maximum thrust of 122.1kN. The mid-level reheated SFC was 63.5 g/N-h and the maximum reheated SFC was 230.6g/N-h.

During the development stage of WS6, total of 10 demonstrators were fabricated. Total test time of the components and integral unit amounted to 30000 and 300 hours, respectively. For three times it had qualified the 24-hour pre-flight test and the designed functions were met. It marked an important milestone of the development of jet propulsion technology in this country. This important technology has also laid the foundation for the transition from imitation to independent development of jet engines. The realization of development of WS6 had emphasized the importance of model designation and control, and the research and development of aviation science. The development of WS6 was terminated because the aircraft development project was cancelled.



(key: 1 - fan

2 - high pressure compressor

3 - combustion chamber

4 - outer spool

5 - turbine

6 - augmented combustion chamber)

GENERAL STRUCTURE ARRANGEMENT

The two rotors of WS6 were supported on the 5 axle bearings. The high pressure rotor had two supporting bearings; the front one was the rolling ball bearing which was installed on the conical wall of the axle bearing of the intermediate engine cabinet, and the rear one was the rolling rod bearing which was installed on the axle bearing seat of the intermediate engine cabinet. The rear supporting bearing adopted the squeezing oil-frame vibration damping device in order to reduce the vibration of the engine. The low pressure rotor had three supporting bearings; the front one was the rolling rod bearing which was installed on the front engine cabinet and was supported by the stator blades of the first-level fan, the middle one was the rolling ball bearing which was installed on the front axle neck of the high pressure turbine, the read one was the rolling rod bearing which was installed on the seat of the axle bearing of the intermediate engine cabinet. In order to reduce the axial force applied on the ball bearings, pressure-damping and loaddamping devices were installed to the rear of the third stage plate of the fan and the eleventh stage plate of the high pressure compressor.

The main installation section, composed of ball head and ball seat, was on the same level as the sides of the intermediate cabinet and was higher in elevation by 50cm. The ball seat was tightly matched and fixed to the intermediate engine cabinet with threaded rods. Structure of this kind showed desirable features such as good strength, good stiffness, low temperature, close to the thrust axle bearing, reasonable transport of force, and low weight.

The auxiliary installation section was supported on the force-bearing ring of the outer spool. The force-bearing ring composed of four pairs of shearing rod along the tangential direction which were connected to the intermediate engine cabinet, forming a three-layer force-bearing structure. The two hanging support rods were fixed to the longer arc at the top of the force-bearing ring. The supporting rods were near the tangential shearing rods so that the thermal stress could be greatly reduced and the incompatibility between the thermal expansions in the axial and radial directions of inner/outer spool can be alleviated. In this way, the force in the direction of the accelerating axle would not be transmitted to the inner spool.

COMPONENTS

Fan

There were three stages of fans; the first stage was the sound-trespassing stage and the others were the soundless stages. At the tip of the blades of the first stage rotor was the dove-tail tenon, at 2/3 length of the blade was the protruding shoulder. The plate and the front of the axle were tightly fixed and torque was transmitted through matched teeth. The secondary and third stage plates were fixed to the axle with awl caps and were fastened with tremendous axial force to ensure proper positioning during operation; drum cap was used for connection and transmission of torque. The secondary and third stage blades were connected to the plates with nail tenons. Under the condition of low speed rotation, free vibration of the blades was possible when excited and, as a result, basic resonance vibration could be avoided. Furthermore, the centrifugal force on the blades could compensate for the tangential torque driven by compressed air so that the bending stress at the root of the blades exerted by this torque could be eliminated.

There were 34 blades for the first stage stator, with 30 of them solid and 4 of them thickened hollow blades. Two of these four hollow blades were used for supply and retrieve of oil for the front axle bearing and for the other two, one of them was used for venting of oil reservoir and the other one for circulation of hot air from the high pressure turbine outlet. The hot air was used for de-icing of the air intake and pressurization of the lubrication sealing device. The secondary and third stage stators exhibited hollow laminated structure and were filled with bubble polymer filling to stiffen the blade and reduce the vibration.

Intermediate Engine Cabinet

The intermediate engine cabinet situated between fan and high pressure compressor and composed of eight radial supporting panels, flow distributing ring, and inner and outer casings. The air leaving the fan and entering the intermediate engine cabinet was divided into two streams: one flowed into the outer spool and another flowed into the high pressure compressor.

The intermediate engine cabinet was made of high strength heat-resistance aluminum alloy and was the major force bearing compartment of the engine. The main installation sockets were at the right and left sides of it and the subordinate engine cabinet was directly underneath. Moreover, the central transmitting gear box and the adjustable guided blade (and its control device) at the inlet of the high pressure turbine were all fixed to the intermediate engine cabinet.

High Pressure Compressor

The high pressure compressor composed of 11 stages. Its stator composed of front and rear engine cabinets, inlet guided blades and control device, venting device, and air-flow regulator. The front and rear engine cabinets were connected with screws and longitudinal connecting plane was on the vertical surface. The flow regulators of the first 10 stages were divided into two half-rings and were inserted into the "T" slots of the

engine cabinet. The first and second stage flow regulators came with inner rings while the 3-10 stage flow regulators were not equipped with inner rings. The oblong air venting holes were found on the outer ring of the fifth stage flow regulator and when the venting ring was opened, a fraction of the air in the spool might be released through venting hole and the oblong hole and flowed into the outer spool. The outer ring of the outlet flow regulator was inserted into the "T" slot of the diffusion engine cabinet and the inner ring was connected to the combustion chamber with screws. The control mechanism of the inlet guided /34
blades composed of inner and outer parts. The venting control device was coupled with the control mechanism of the inlet guided blades. The angle of the inlet guided blades and the opening/closure of the venting ring was controlled by the conversed rpm of the high pressure compressor.

The first and second stage rotor blades of the high pressure compressor were fixed to the plate with rivet nail tenon while dove-tail tenon was used for all the other stages. The plate, drum, and axle of all the stages were all connected with stubby axial high-precision screws. Drum axle was fixed to the rotor of the high pressure turbine with long axial screws.

Combustion Chamber

The circular-ring combustion chamber composed of 10 flame emitting torches with air inlets, 10 combustible air guide tubes, 10 centrifugal dual-nozzles with fuel supply, 2 high-energy ignition mouthpieces, and the inner and outer engine cabinets.

The flame emitting torches and combustible air guide tubes were fixed to the outer casing with screws and positioning pins. The rear of the flame emitting torches was supported on the inlet of the combustible air guide tube and during operation, free expansion was permitted towards the rear. The combustible air guide tubes were supported on the inner/outer ring of the direction guiding device of the first stage turbine and free expansion was permitted towards the rear.

The nozzles were fixed to the outer wall of the diffuser with four screws each. The manifold of the main and auxiliary oil lines entered from the outer spool and were input to the fuel distributor via two paths, each distributor was then connected to the main and auxiliary oil lines of the five nozzles to ensure even distribution of fuel. Two high-energy nozzles were attached to no.4 and no.7 flame emitting torches and kerosene was ignited directly.

Because of the need of assembling flame emitting torches, the outer compartment of the combustion chamber was divided into two sections, the front section was the outer wall of the diffuser and the rear section was a straight cylindrical casing. The inner compartment was not divided and its front section formed the inner wall of the diffuser.

Turbine

There were two stages of high pressure turbines. The guide blade and working blade of the first stage turbine were air-cooled precision-casting blades. In order to reduce vibration and blade tip erosion. the working blades of the two stages of turbines were all crowned. Each blade was connected to the plate via three pairs of tenons fir-tree structure. Plate, axle, and drum were connected with long screws.

The cabinet of high pressure turbine adopted the integral welding structure. The guide blades were inserted into the corresponding slots of the engine cabinet through the protrusion at the front.

There were 2 stages of low pressure turbines and all the working blades were crowned. Each blade was connected to the plate via three pairs of tenons of fir-tree structure. The low pressure turbine was also an integral welding structure and was divided into two sections. The second stage guide blades were installed in the front engine cabinet while the honeycomb structured outer ring of the second stage turbine was installed in the rear engine cabinet.

Augmented Combustion Chamber

The parallel air intake plan was adopted. The augmented combustion chamber composed of 2 stages of diffusers, dual-layer combustion section, and the stageless, adjustable convergent tail nozzle.

The front section of the diffuser/compressor and the outer spool, and the rear section and the combustion section were all connected with screws. Flame stabilizers were installed at the outlet of the diffuser/compressor. In the interior of the air-mixture boundary layer of the inner/outer spools a main stabilizer was found with a ringlike, dual-wall structure. The action in the combustion chamber was triggered by the semiconductor high-energy nozzles. In the inner spool air stream were two ring-type stabilizers. The three rings of stabilizers were connected with flame-transmitting trough. To the front of the stabilizers were the fuel manifold with two rings of nozzle rail and four rings of nozzles. The fuel supply to the augmented combustion chamber was divided into six sections and each section contained main and auxiliary oil lines. The purpose of supplying fuel to the augmented combustion chamber via a scheme of various-sections/various-pressures was to ensure a broad range of stable working condition and high combustion efficiency. The stabilizer and fuel manifold were both fixed to the outer wall of the diffuser/compressor with tensile bars.

The combustion section was equipped with full-length vibration-damping, heat-resisting shield to eliminate high-frequency vibration combustion and to reduce the wall temperature of the combustion section. The shield was fixed to the casing of the combustion section with longitudinal rivets and free thermal expansion was allowed when heated.

The tail nozzle composed of adjusting baffles, adjusting baffles, and one adjusting ring It was driven by six hydraulic actuators. Since the driving mechanism was that of the turbine/turbine-rod transmitting mechanism, the synchronization of the actuators was very good.

SYSTEM AND AUXILIARY COMPONENTS

Auxiliary Component Transmitting System

This system composed of the intermediate transmitting gear box, auxiliary component transmitting box, and low-pressure transmitting box. The intermediate transmitting gear and the auxiliary component transmitting gear were the spiral conical gear with 0 degree of spiral angle. The auxiliary component cabinet was installed underneath the engine with main fuel regulator, augmented fuel pump, lubrication oil auxiliary component, centrifugal ventilation device, blade adjustor, air turbine starter, fuel pressurizer, constant-speed AC generator, and hydraulic pressure pump. On the low-pressure transmitting cabinet were the low-pressure rotor speedometer and fan speed limiter.

Electrical System

The purpose of the electrical system was to ensure the smooth startup and function of the engine. It composed of the starting system, ignition system (main ignition and augmenting ignition), air-release band control system, turbine front temperature limiter, tail nozzle area controlling system, and augmenting flame probing system. The special features of this system were the capability of automatic startup with a very short startup time; adoption of air turbine starter, high-energy ignition device and high-energy nozzle; and the constant condition of the augmenting electrical nozzles during augmenting periods.

Adjusting System

This system composed of main adjusting system, augmenting fuel adjusting system, and nozzle area adjusting system. Special features of this system included multi-function, high precision, ample fuel supplying capability, dependability, good adaptability, and good accelerating properties.

Lubricating System

The reverse circulation scheme was adopted for the lubrication system which composed of fuel supply system, fuel back-flow system, and venting system. The heat diffuser was installed on the oil line of the pressurized pump. Devices capable of automatic adjusting of the outlet area was installed at the outlet of the vent line of lubrication oil reservoir to ensure adequate high-altitude functions. The axle bearings at various supporting points were the contacting carbon cycle sealing device.

MATERIALS

Titanium alloys were used in the cold spots of the engine such as the inlet air-regulating cap, fan components, first six stages of high pressure compressor cabinets and rotor blades, external spool, augmented diffuser/compressor casing. Components made of titanium alloys amounted to 122 categories and total weight amounted to 1/4 of the weight of the engine.

Various high temperature alloys were used in the hot spot components such as combustion chamber, turbine, and augmented combustion chamber (except for walls of diffuser/compressor). Various stainless steels and alloy steels were used in the transition regions between cold and hot spots such as blades of the last five stages of high pressure turbine, high/low pressure rotor axles, and gear transmitting components. Furthermore, magnesium alloy was used in the auxiliary component casing and carbon/graphite was used in the main axle seals.

STRUCTURAL DEFECT AND COPING MEASURES

Mechanical Wear

During the initial test periods, many incidents of wear of /35
rotating parts and stators occurred. Most of the wear occurred between the sealing comb gear of the rotor and the stator sealing ring. Through stiffening of the sealing ring and modification of comb gears (increase in the tooth height and decrease in the tooth thickness), this wear defect was alleviated.

High Vibration

During test periods, the vibration of the engine was excessive and caused great safety concern. At low speed, vibration was mainly a result of mechanical wear and, through the alleviation of mechanical wear problem, the problem of low speed vibration was alleviated.

At intermediate speed, a critical speed of the low pressure rotor was detected and resulted in the excessive vibration of the engine. Two measures were taken to cope with this problem: the elastic support provided by band-squeezing oil-film axle bearing was adopted at the rear supporting point of the low pressure rotor, and the drum axle connecting the three sections were changed to the slender long axles. At high speed, the vibration of the high pressure rotor was found excessive. This problem was alleviated through the increase of the connecting stiffness, improvement of balance, and adoption of squeezing oil-film damping at the rear supporting point of the high pressure rotor.

Wear of Axle Bearings

Several wear incidents occurred during testing, the severest being the wear of the middle rolling ball axle support bearing of the low pressure rotor. Significant improvement was achieved by changing the scheme of oil supply to the axle bearing, modification of internal flow system of the engine and structural /36
design of the ball bearing.

FIRST GENERATION FULL PRESSURE HELMET FOR CHINESE PILOTS

The high performance supersonic fighter F-8, designed by this country, is a mid to high altitude multirole fighter. When the altitude is 20 kilometers or higher, atmospheric pressure was lowered to 5.47 kPa (41 mm-Hg). If a pressure difference of 13.9 kPa (104mm-Hg) were not supplemented, the basic oxygen requirement of the human body can not be satisfied. In other words, if the air tight cockpit were damaged at this altitude, the life of the pilot will be in great danger. The first-generation full pressure helmet was designed with the F-8 pilots in mind.

The basic design plan for the first-generation full pressure helmet was based on the requirement of the new aircraft and suggestions of its pilots: it acted as the protective helmet at low to mid altitudes but as the full pressure helmet at high altitudes. During flight, if the air tight cockpit were in normal condition, the observation plate would be in an opened state; however, if the air-tight cockpit were damaged, the observation plate would be closed automatically.

There are many technical difficulties related to the design plan mentioned above such as the supply of oxygen when the observation plate is opened and closed, the effect of the impact on the pilot when the observation plate is closed, design of the control circuitry for the automatic closure of observation plate, and plating of metallic conductor film on a glass substrate.

After hundreds of model manufacturing and verification and nearly a hundred actual flight tests, the design of this type of helmet was verified by the aviation product verification agency and was designated as TK-4 opened full pressure helmet (see figure).

TK-4 Opened Full Pressure Helmet

As a new generation protective equipment, TK-4 opened full pressure helmet was already used by pilots flying the new aircraft such as F-7 III, F-8 II, FT-7. When the altitude was less than 25km and the cockpit was air-tight, the observation plate was in an opened state. Oxygen supplied from the regulator and was fed to the pilot through oxygen mask. When the air-tightness of the cockpit was lost, the observation plate was closed automatically and the helmet was in an air-tight state. Oxygen quickly filled the helmet chamber through oxygen mask and pressurized oxygen was supplied. In this way the physiological effect of high altitude air swelling and low pressure would be avoided. At 0-6km altitude, supply of oxygen of the oxygen mask of the full pressure helmet was based on the lung-type operation and no residual pressure remained in the mask. At 6-12km altitude, a residual pressure of 343Pa (35mm-Hg) remained in the mask; higher than 12 km altitude, pressurized oxygen is supplied and the total pressure was maintained at 19.30kPa (145mm-Hg).

Used along with the pressure compensating flight suit, the TK-4 full pressure helmet would protect the safety and necessary function of the pilot under the following conditions:

1. extended periods of flight at altitude less than 25km and in the air-tight cockpit or at altitude less than 12km and in non air-tight cockpit;

2. if the altitude is between 12 and 25km and air-tightness of the cockpit is lost, observation plate will close automatically to ensure supply of pressurized oxygen for 5-10 minutes;

3. ejection parachuting for a speed less than 1000km/hr is allowed and impact of head-on air current can be balanced.

TK-4 opened full pressure helmet composed of 9 major components: outer casing, observation plate, lowering mechanism, oxygen mask, light filter, full pressure hat, protective hat, tension device, and pipelines. The outer casing was made of glass copper. The lining (both hard and soft) within the helmet was made of polystyrene and was found to have excellent vibration damping characteristics. The observation plate was made of mono-layer organic glass and metallic conducting film was plated in the interior, defogging was achieved by electrical heating. Luminescence and deflection were both avoided and the left-right view was 202 degrees. Searching distance in air was 10km. The helmet was supplied in two sizes with the large size weighted less than 3.5kg and the small size weighted less than 3.3kg.

The automatic control system allowed the observation plate to be closed in case of any one of the three emergency conditions (loss of air-tightness in the cockpit, bailing out through ejection, jettison of cockpit cover). The working principle was that electricity was used to ignite the bailing ordnance of the automatic lowering device and to generate an instantaneous high pressure gas which drove the swing arm mechanism and closed the observation plate. Test showed that about 0.041 second was required for the observation plate to be closed after the micro-closure signal was triggered. This time elapse was far shorter than the time periods required for jettison of cockpit cover or ejection bailing out. Therefore, the technical requirement that the observation plate should be closed before ejection was satisfied.

In order to verify the high speed ejection capability of the safety system of F-8, ejection test was conducted on rocket gliders with speed of 1000-1100km/hr Results showed that the performance of TK-4 full pressure helmet was excellent. Remaining problems mainly lied with weight, comfortableness, and difficulty in wearing and removing. More design effort is needed to cope with these problems.

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